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Cleveland

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(45) **Date of Patent: Feb. 24, 2004**

(54) **SHOCK ISOLATION SYSTEM FOR SPACECRAFT FAIRING**

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(73) Assignee: **The Boeing Company**, Chicago, IL (US)

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(22) Filed: **Feb. 11, 2002**

(65) **Prior Publication Data**

US 2003/0150959 A1 Aug. 14, 2003

(51) **Int. Cl.**[7] **B64G 1/10**
(52) **U.S. Cl.** ..... **244/158 R**
(58) **Field of Search** ..... 244/158 R, 161, 244/118.2, 63, 131

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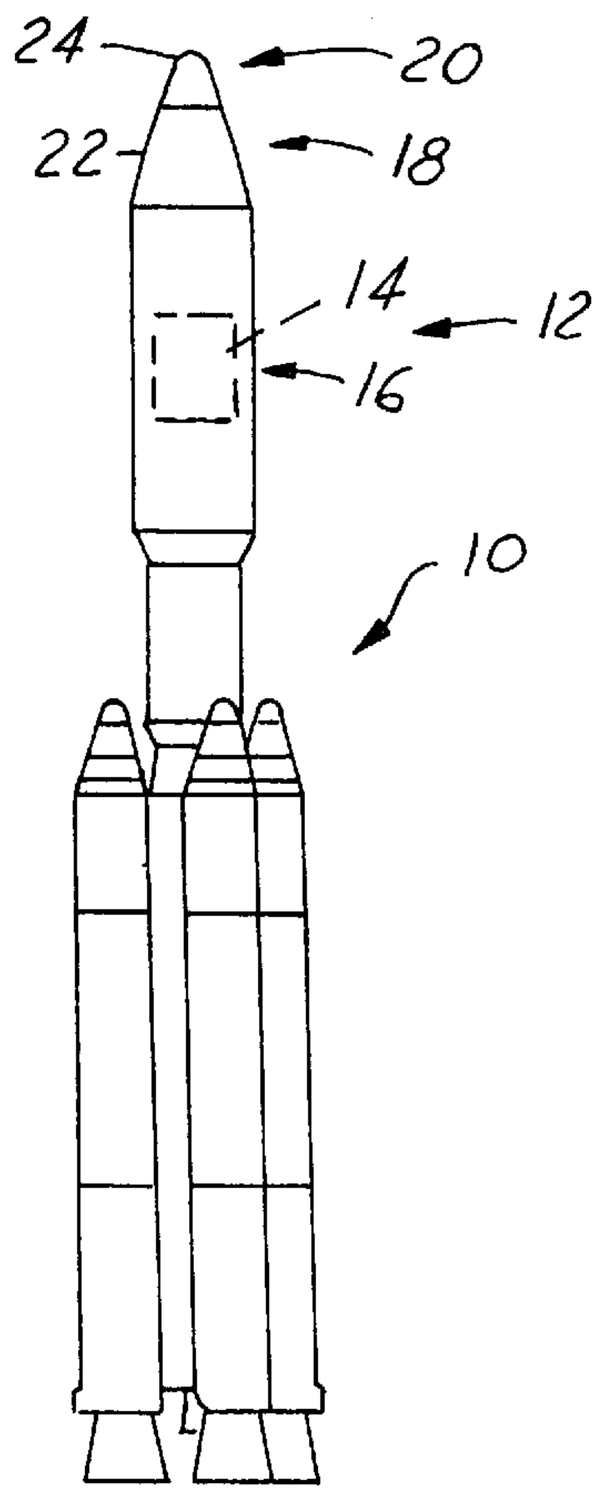
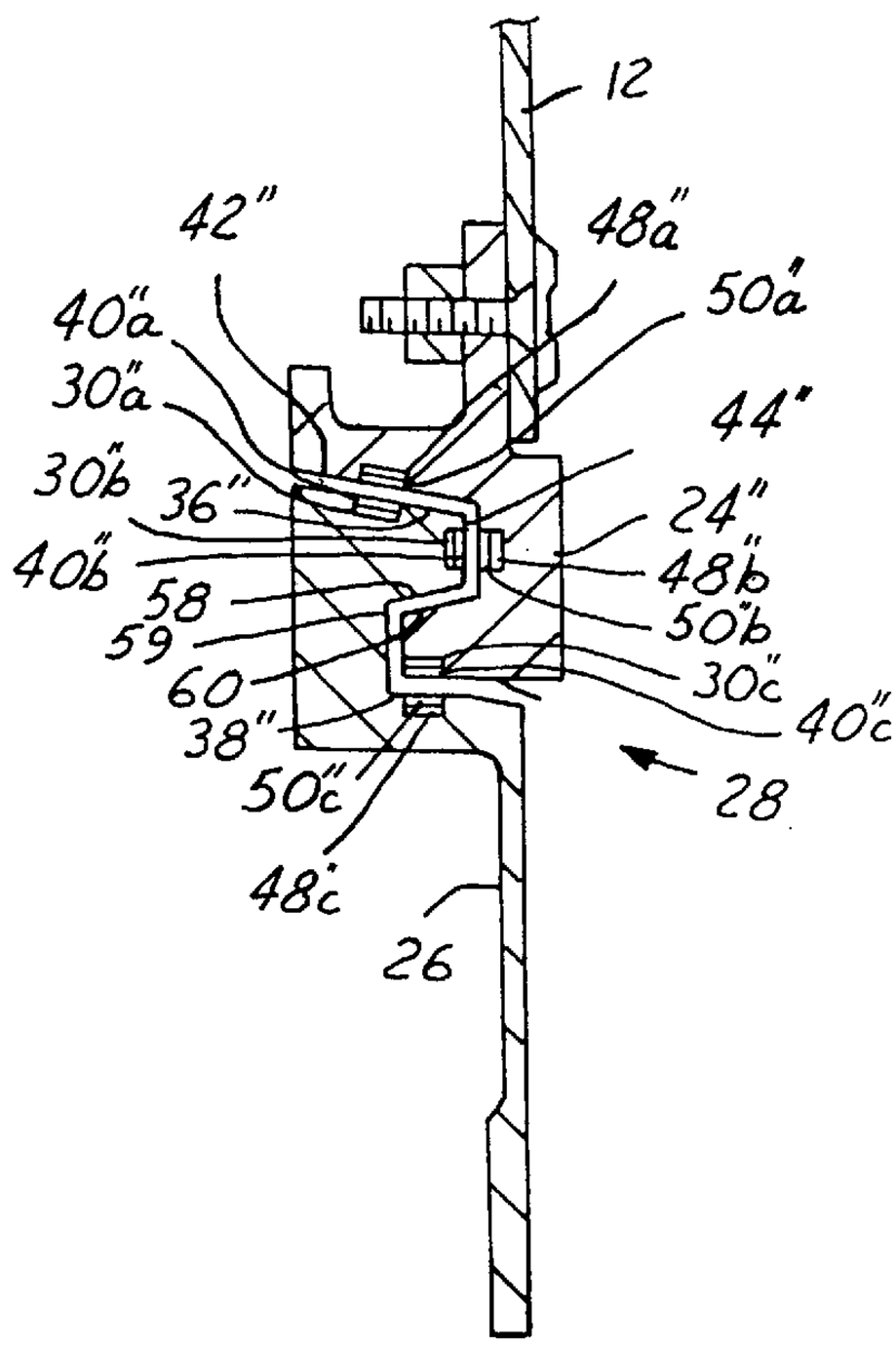
(74) *Attorney, Agent, or Firm*—Terje Gudmestad

(57) **ABSTRACT**

A launch vehicle assembly has a launch vehicle body (**10**) having a first slot (**48***a*) therein. A first magnet (**50***a*) is disposed within the first slot (**43***a*). A fairing assembly (**12**) is positioned adjacent to the vehicle body (**10**). The fairing assembly (**12**) has a second slot (**30***a*) therein positioned opposite the first slot (**48***a*). A second magnet (**40***a*) is disposed within the second slot (**30***a*) so that the second magnet (**40***a*) repels the first magnet (**50***a*).

16 Claims, 4 Drawing Sheets





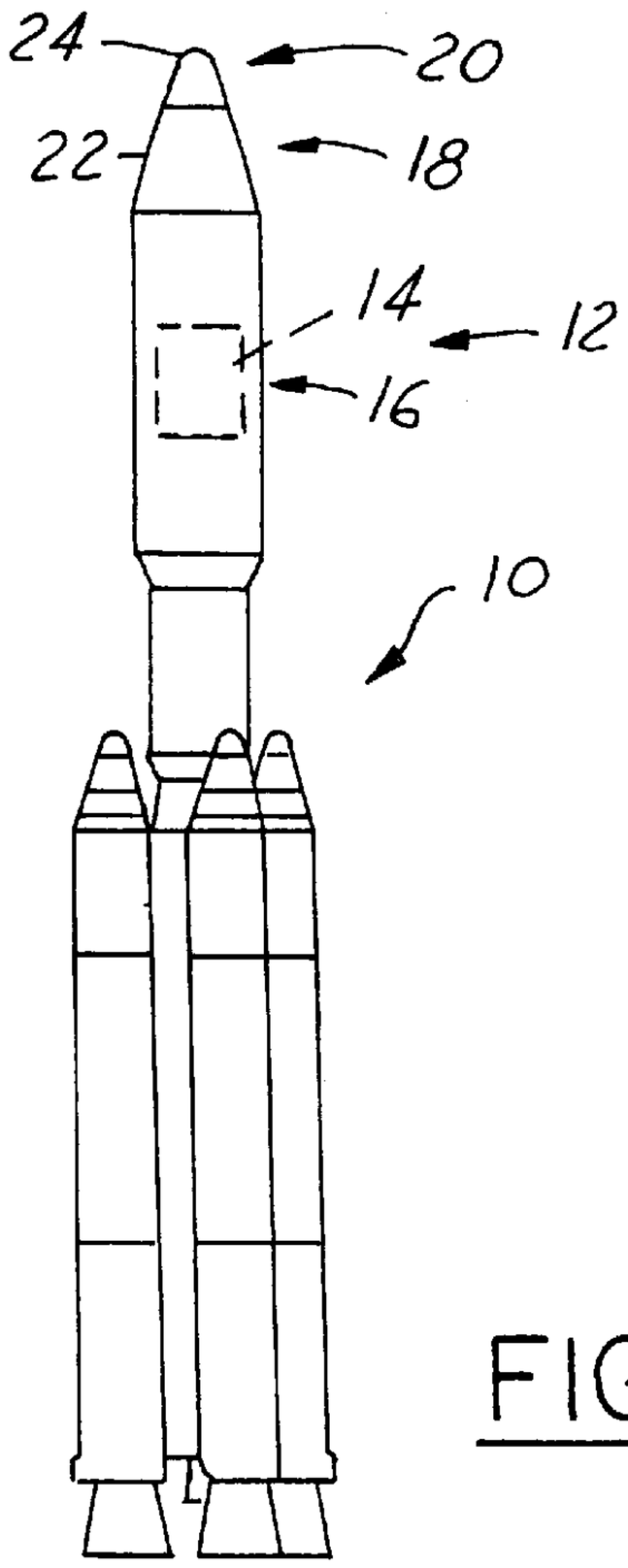


FIG. 1

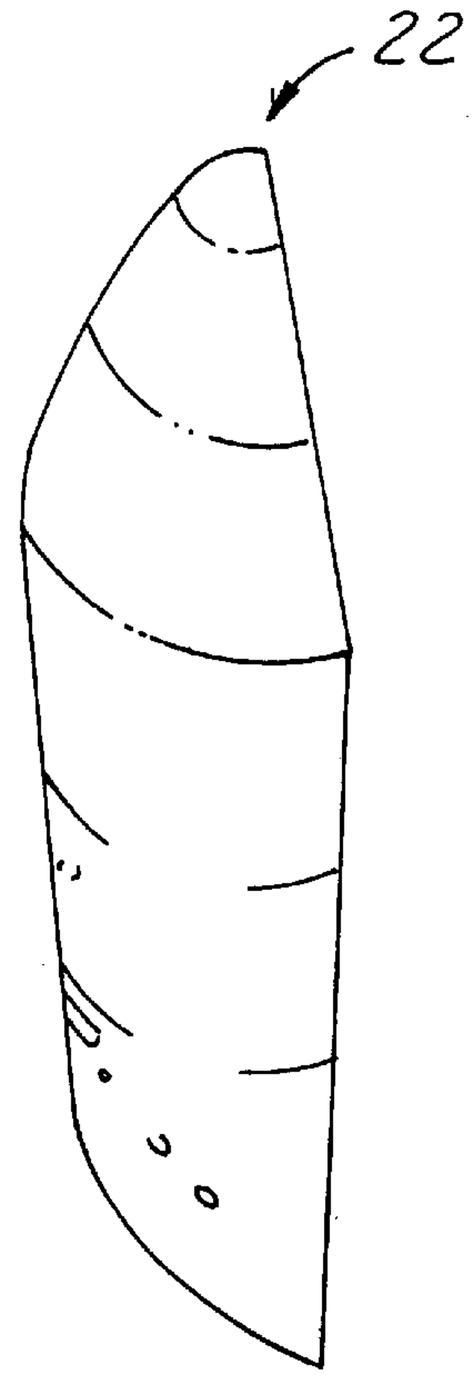


FIG. 2

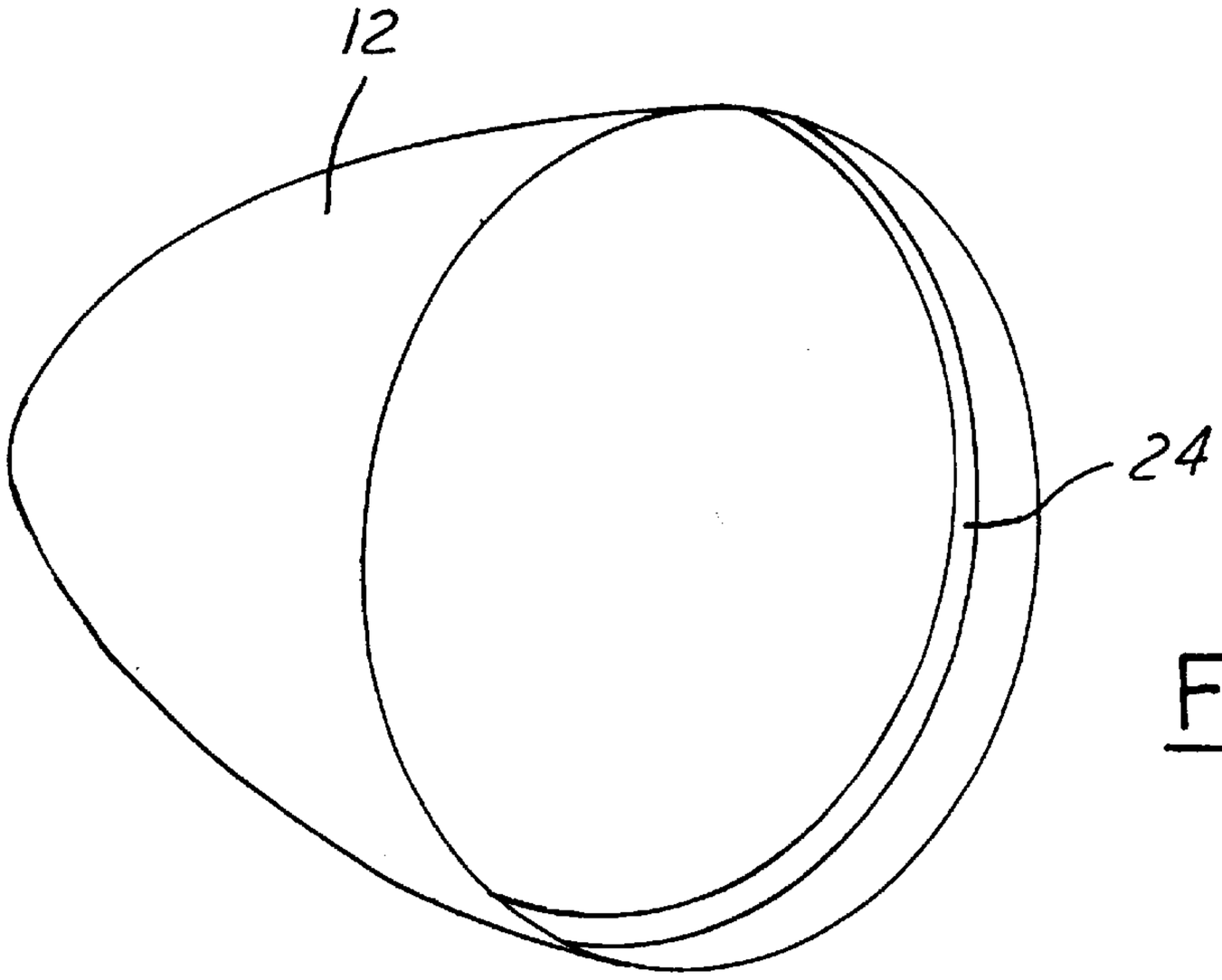


FIG. 3

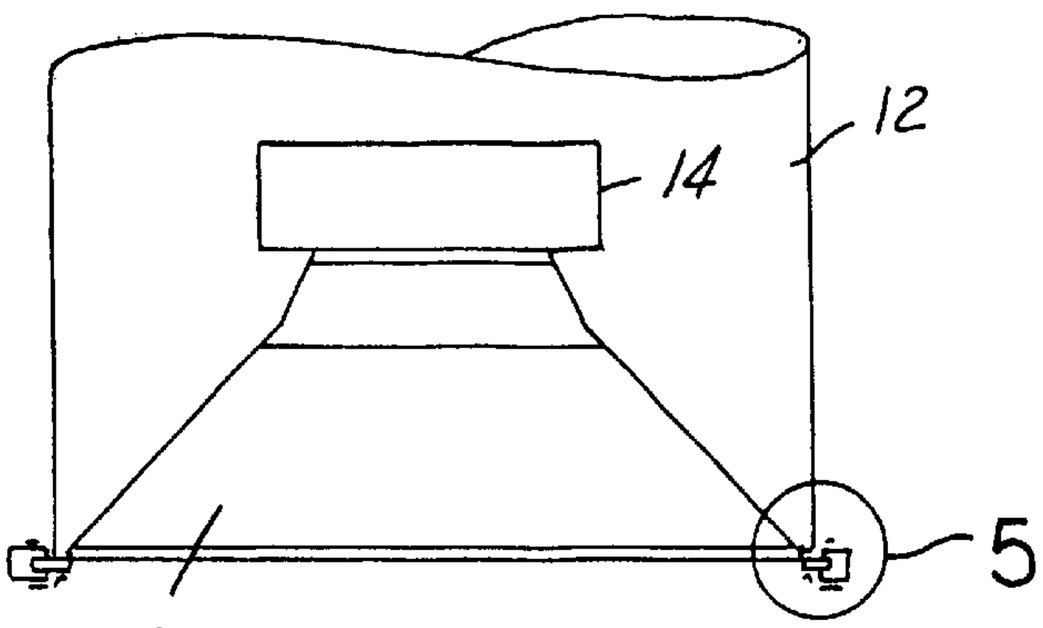


FIG. 4

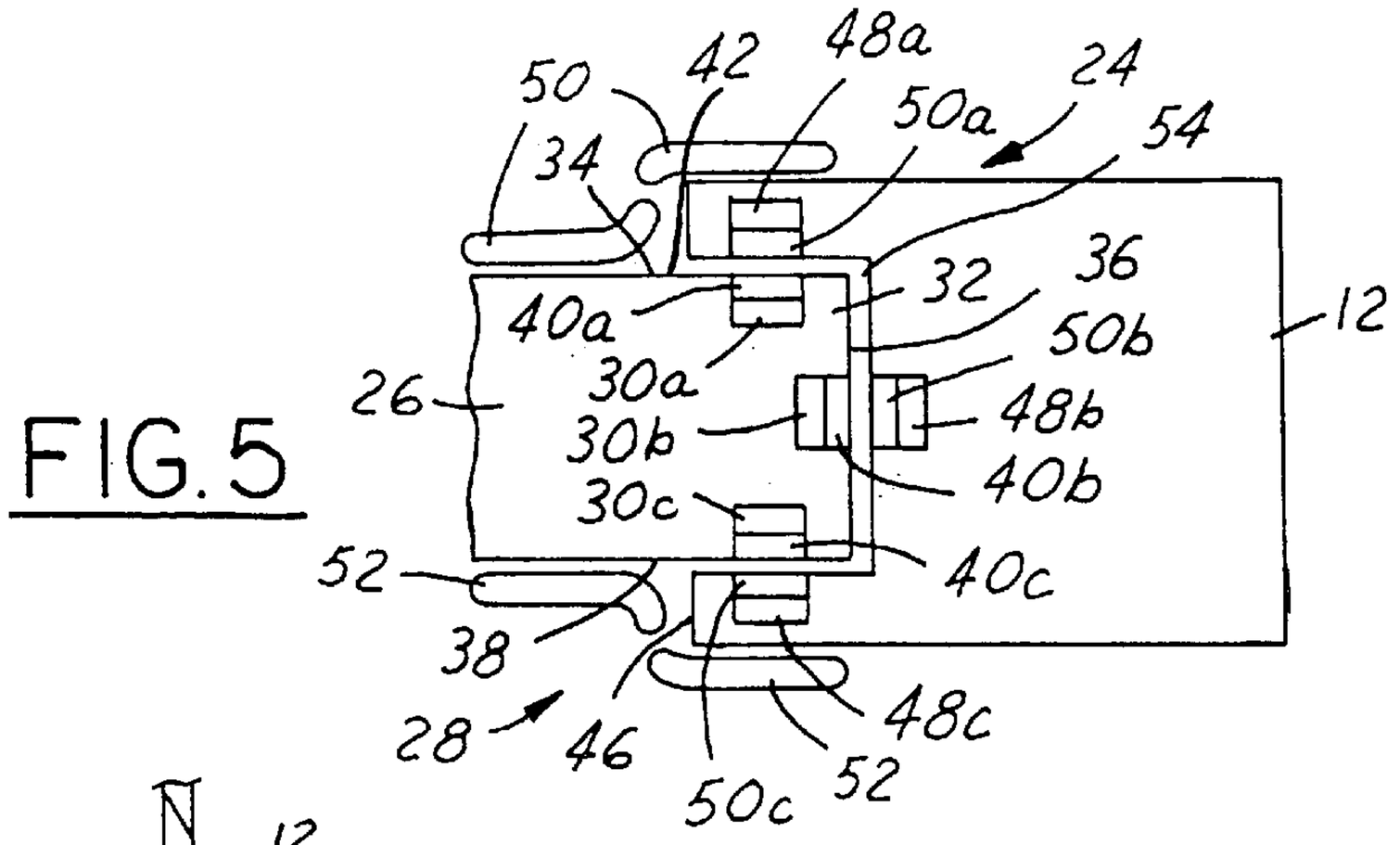


FIG. 5

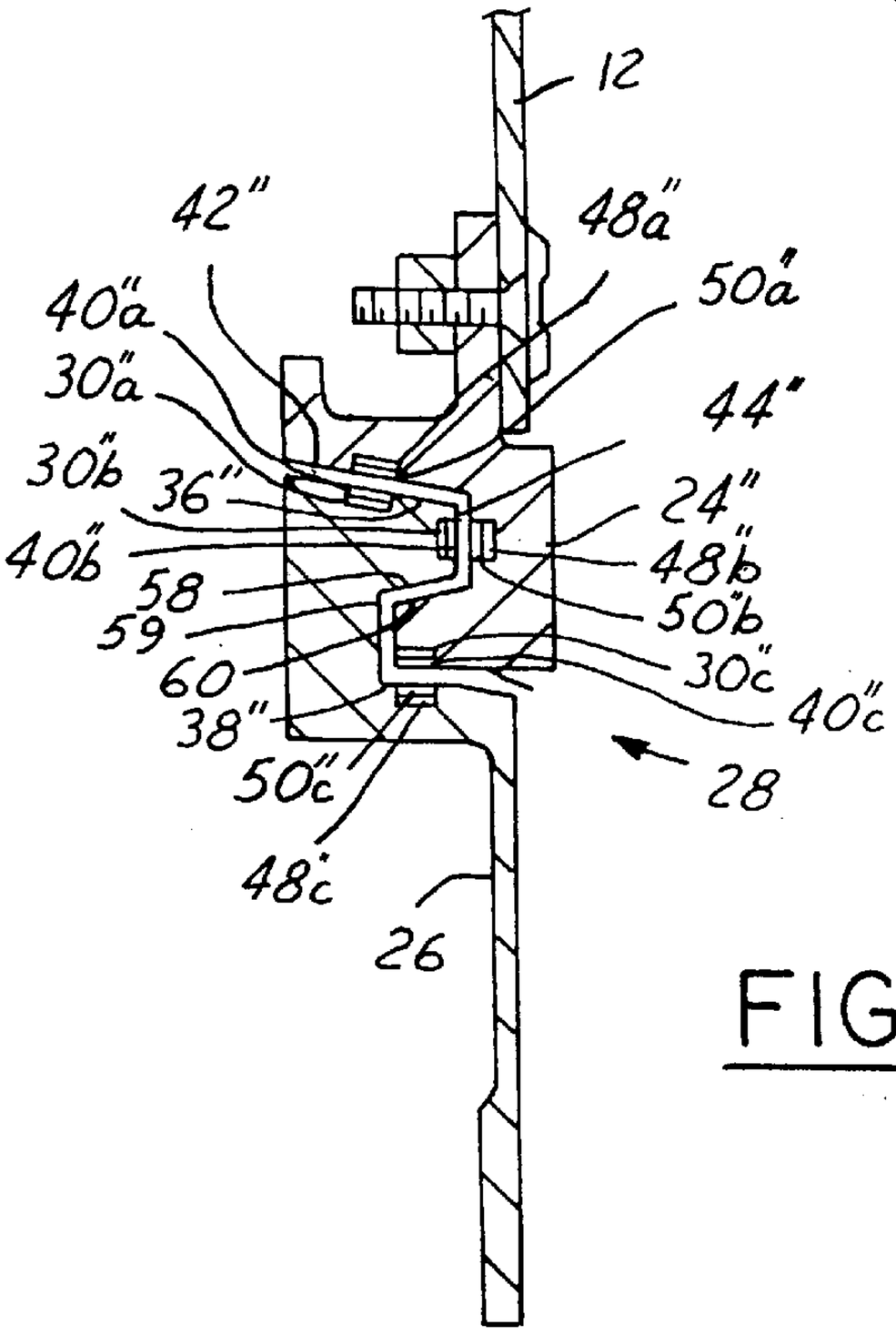


FIG. 7

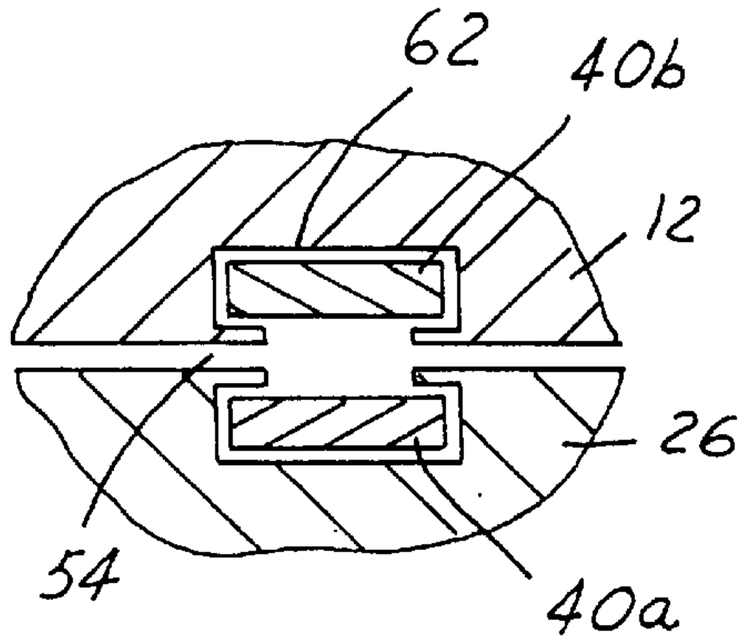


FIG. 8

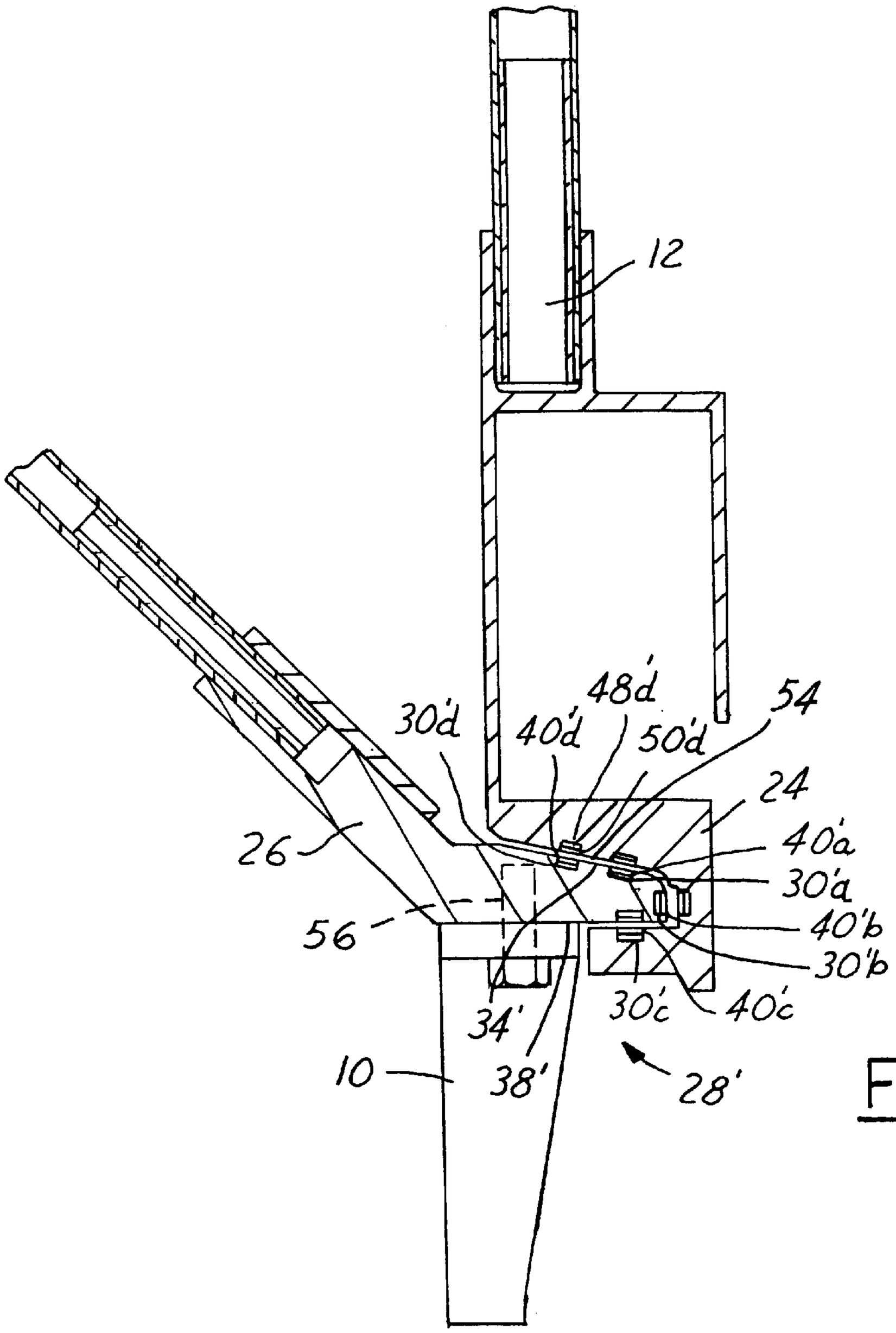


FIG. 6

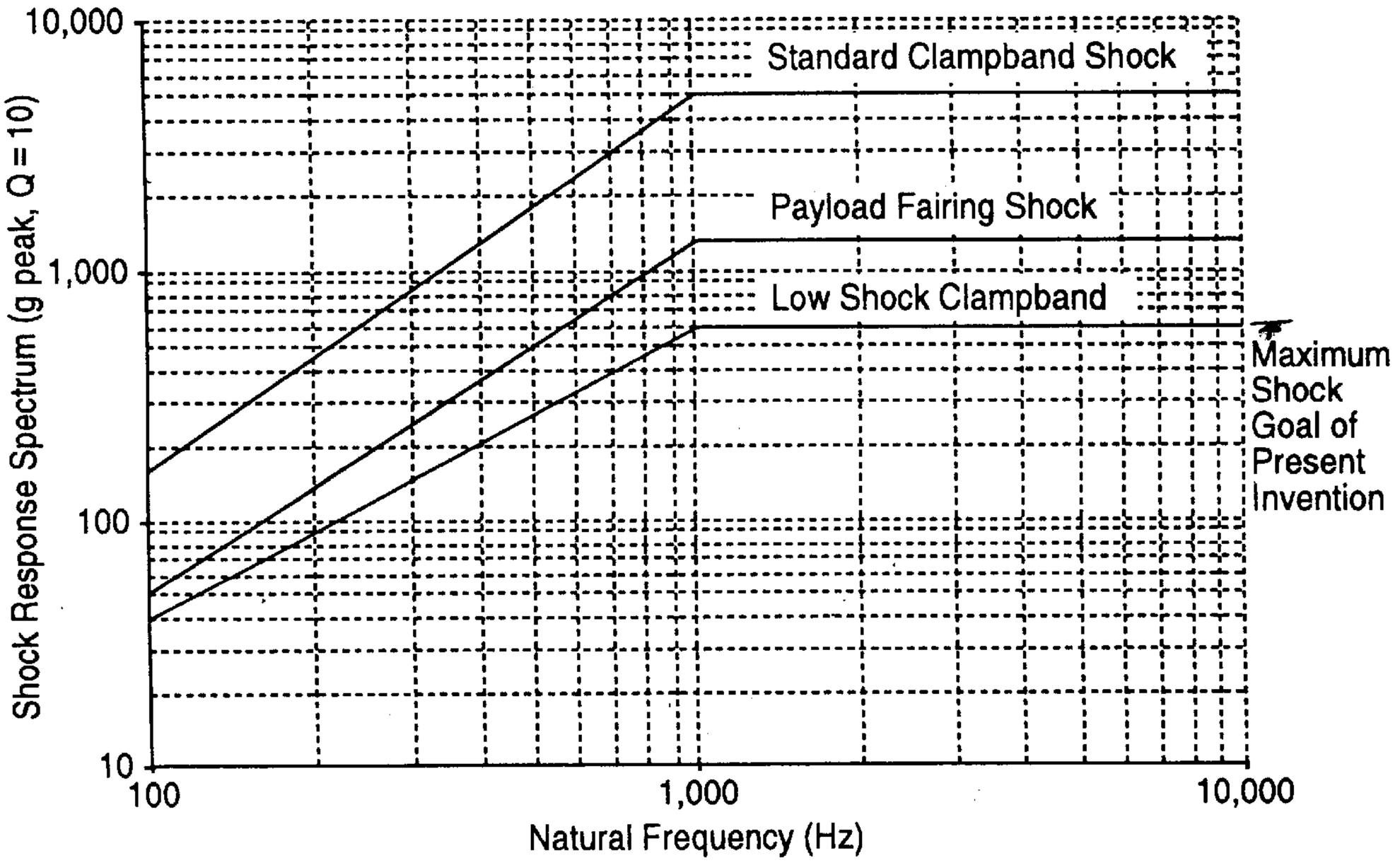

10,000
1,000
100
10
Shock Response Spectrum (g peak, Q = 10)
100
1,000
10,000
Natural Frequency (Hz)
Standard Clampband Shock
Payload Fairing Shock
Low Shock Clampband
Maximum Shock Goal of Present Invention

FIG.9

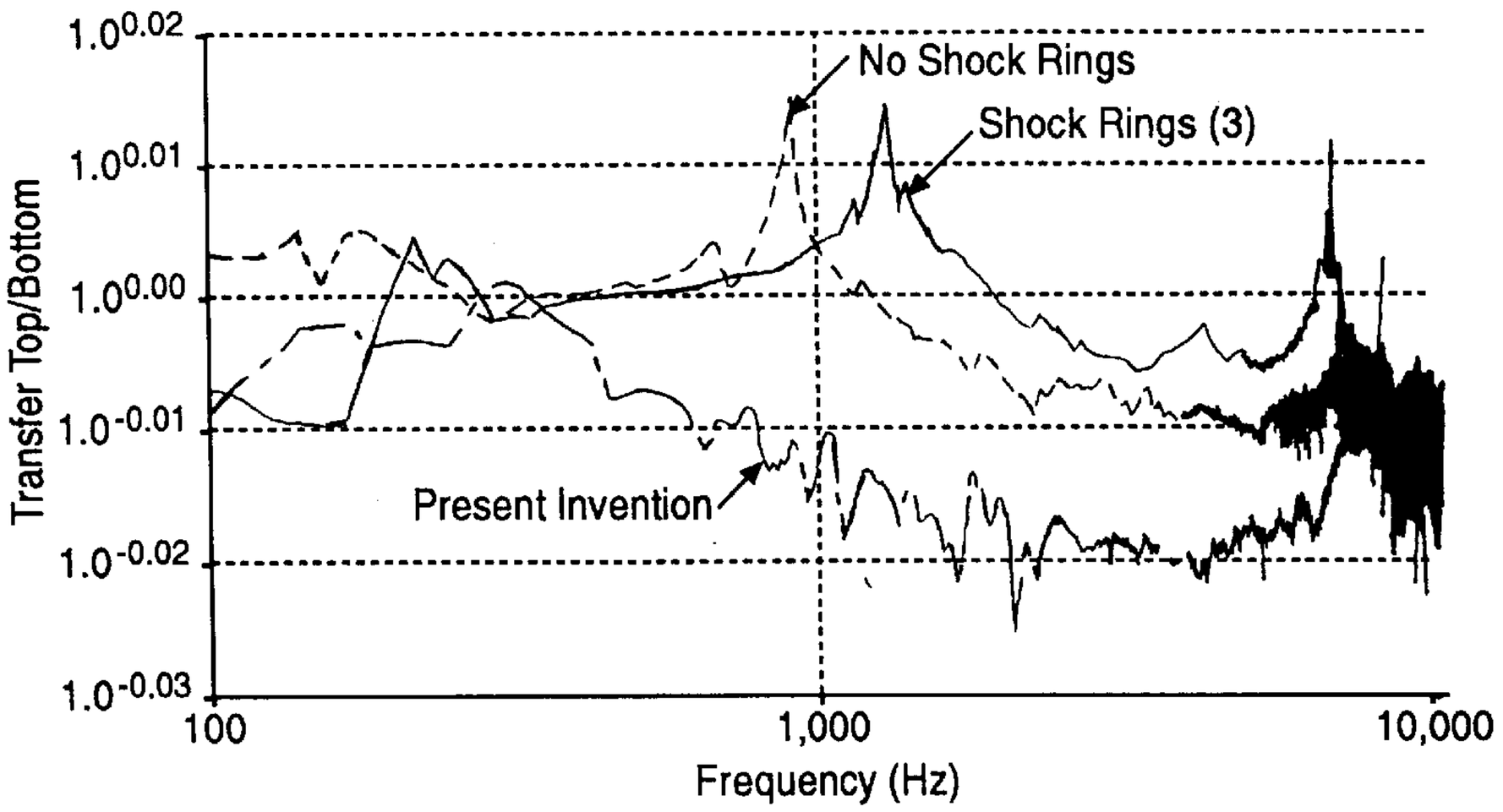

1.0^0.02
1.0^0.01
1.0^0.00
1.0^-0.01
1.0^-0.02
1.0^-0.03
Transfer Top/Bottom
No Shock Rings
Shock Rings (3)
Present Invention
100
1,000
10,000
Frequency (Hz)

FIG.10

SHOCK ISOLATION SYSTEM FOR SPACECRAFT FAIRING

TECHNICAL FIELD

The present invention relates generally to payload fairings for launch vehicles and, more particularly, to an interface between the fairing and the launch vehicle.

BACKGROUND ART

A launch vehicle is used to launch a payload into the orbit around the earth. The payload, however, needs protection from the atmosphere created at launch. High temperatures and pressures created may damage a sensitive payload. A fairing is typically used to protect the payload. The fairing surrounds the payload in the nose portion of the launch vehicle. Typically, the fairing is detachably mounted to the upper stage of the launch vehicle. As soon as the rocket leaves the atmosphere, the fairing is explosively separated from the launch vehicle and discarded.

Spacecraft are subjected to a broad range of potentially damaging environmental conditions during flight, including shock. The two highest sources of shock to the payload occur during payload fairing separation and payload separation. Traditionally, a mechanical shock attenuation device such as shock rings are employed between the fairing and the payload attachment hardware. This, however, leaves a direct path in place for shock transmission. Although the shock rings employed soften the shock to the payload, they are operationally fragile, cumbersome to install, and add unnecessary weight to the launch vehicle. Further, modern spacecraft have more highly sensitive components than previous spacecraft, and therefore must be designed to sustain high flight shock and vibration environments, at the expense of useful payload-to-orbit mass. Spacecraft must be subject to expensive time-consuming ground tests to validate payload capabilities against severe flight environment including random vibration, acoustics and shock. The spacecraft separation via a clampband is typically the dominant shock source to which components are qualified. Over the past several years, spacecraft manufacturers have funded the development of several low shock clampband systems to fly on various launch vehicles. Spacecraft are typically qualified to this environment by performing two clampband release tests. If a low shock clampband is used, the fairing now becomes the dominant shock source. Spacecraft must still be qualified to higher g's via the clampband release test because it would be to difficult and expensive to qualify the spacecraft using a full scale fairing separation test to envelope the shock.

It would therefore be desirable to provide a structure that reduces the amount of shock on the payload during fairing separation.

SUMMARY OF THE INVENTION

The present invention provides a magnetic interface between the payload fairing and the launch vehicle whereby the fairing is levitated a distance above the launch vehicle when the fairing is separated from the launch vehicle.

In one aspect of the invention, a launch vehicle assembly has a launch vehicle body having a first slot therein. A first magnet is disposed within the first slot. A fairing assembly is positioned adjacent to the vehicle body. The fairing assembly has a second slot therein positioned opposite the first slot. A second magnet is disposed within the second slot so that the second magnet repels the first magnet.

In another aspect of the invention, a method of operating a launch vehicle comprises:

positioning a payload fairing adjacent to a launch vehicle body;

contacting the payload fairing with the launch vehicle body above a predetermined force on the payload fairing;

levitating the payload fairing relative to the launch vehicle body below a predetermined force on the payload fairing; and

after levitating the payload fairing, releasing the payload fairing from the lunch vehicle.

One advantage of the invention is that by mitigating shock on the payload during fairing release, less damage to payload is possible. Also, launch and launch vehicle performance does not need to be sacrificed due to added weight of previously known adapting methods.

Other advantages and features of the present invention will become apparent when viewed in light of the detailed description of the preferred embodiment when taken in conjunction with the attached drawings and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side elevation view of a launch vehicle according to the present invention.

FIG. **2** is a perspective view of a portion of a fairing according to the present invention.

FIG. **3** is an inside view of a fairing according to the present invention.

FIG. **4** is a high level cross-sectional view of the interface of the payload attachment fitting and the fairing.

FIG. **5** is a cross-sectional view of the interface of FIG. **4**.

FIG. **6** is a cross-sectional view of a second embodiment of the fairing/payload attachment fitting interface according to the present invention.

FIG. **7** is a cross-sectional view of a third embodiment of a fairing interface according to the present invention.

FIG. **8** is an enlarged cross-sectional view of a preferred embodiment of the magnet positions according to the present invention.

FIG. **9** is plot of shock response spectrum versus the natural frequency of a standard clampband shock, a payload fairing shock, a low shock clampband, and the magnetic interface of the present invention.

FIG. **10** is a plot of the transfer shock illustrating no shock rings, shock rings, and the magnets of the present invention.

BEST MODES FOR CARRYING OUT THE INVENTION

In the following figures, the same reference numerals will be used to identify the same components. While the present invention is illustrated with respect to several embodiments having several cross-sectional views and numbers of magnets, the present invention is equally applicable to various cross-sectional views and numbers of magnets.

Referring now to FIGS. **1** and **2**, a launch vehicle **10** is shown which includes a shroud or fairing **12**. Fairing **12** surrounds a payload **14**, which is generally a satellite or other space vehicle. It should be understood that any suitable payload may be launched and that any type of launch vehicle may be utilized in the launch. Fairing **12** generally includes three portions; a cylindrical portion **16**, a nose cone portion **18**, and a nose cap portion **20**. Fairing **12** is made up of

sectors **22**, one of which is shown in FIG. **2**. Fairing **12** surrounds the payload to protect it before and during launch until a predetermined point in the launch sequence. The predetermined point may be that sufficient altitude has been achieved, for example. At that predetermined point, fairing **12** is discarded or deployed and sectors **22** are forced to separate and fall away from payload **14**.

The payload needs protection from the atmosphere created at launch. The high temperatures and pressures created can damage the sensitive payload. Further, the payload must be protected from the shock of releasing the sectors **22** at the predetermined point during the launch sequence. Antennas or other appendages may easily be damaged from the shock of releasing the fairing. The inventive fairing **12** of the present invention is constructed to dampen the shock on payload **14** when deploying the sectors **22**.

Fairing **12** is made up of a number of sectors **22**. Typically, two or three sectors **22** are utilized, but those skilled in the art will recognize that various numbers of sectors may be used. Together sectors **22** form the protective housing for payload **14**. Sectors **22** are connected to each other to form fairing **12** by conventional means. In the preferred embodiment, the connection is made by using an energetic separation joint common to spacecraft fairing structures. The separation joint hardware is typically bonded or mechanically attached to the edges of sectors **22**. The connections are sealed to provide a secure arrangement until fairing **12** is deployed away from payload **14**. In one embodiment, compressed gas or explosive devices are used with connectors so that when desired the compressed or explosion separates sectors **22** from one another and away from the payload. The explosive devices may be detonated remotely when the vehicle reaches a predetermined altitude and the sectors fall away from the payload. The payload is then exposed.

Referring now to FIG. **3**, a perspective view of the inside of fairing **12** is illustrated. As will be further described below, fairing **12** has a ring **24** that extends around the circumference thereof. As will be further described below, ring **24** has magnets therein that cooperate with magnets on the launch vehicle body.

Referring now to FIG. **4**, a high level cross-sectional view of fairing **12**, payload attachment fitting **26**, and an interface **28** therebetween. Further, payload **14** is illustrated coupled to payload attachment fitting **26**. Payload attachment fitting **26** is secured directly to the top stage of the body of launch vehicle **10**. Fairing **12** and payload attachment fitting **26** are generally circular in cross-section and thus have a circular interface **28** extending around the circumference thereof.

Referring now to FIG. **5**, interface **28** is illustrated in further detail. As illustrated, payload attachment fitting **26** has a plurality of slots **30***a*, **30***b*, and **30***c* therein. Slot **30***a* is disposed in a top surface **34** of a lip **32** of payload attachment fitting **26**. Slot **30***b* is disposed in a side surface **36** of lip **32**. Slot **30***c* is disposed in a bottom surface **38** of lip **32**. Three magnets **40***a*, **40***b*, and **40***c* are disposed in respective slots **30***a*, **30***b*, and **30***c*.

Ring **24** of payload fairing **12** has a top surface **42**, a side surface **44**, and a bottom surface **46**. These surfaces are complementary to those of lip **32**. That is, surfaces **42**, **44**, and **46** are generally parallel to those of surfaces **34**, **36**, and **38**. By providing complementary surfaces a gap **54** may be maintained therebetween. Top surface **42**, side surface **44**, and bottom surface **46** have a respective slot **48***a*, **48***b*, and **48***c*. Each slot preferably has a respective magnet **50***a*, **50***b*, and **50***c*.

Magnets **40***a*, **40***b*, and **40***c*, and magnets **50***a*, **50***b*, and **50***c* are preferably formed of neodymium rare-earth magnets. In one constructing embodiment, eight sets of slots, four pairs of opposing slots, were used. Also, various shielding **52** may be disposed around payload attachment fitting **26**, payload fairing **12** and magnets **40***a*, **40***b*, **40***c*, **50***a*, **50***b*, and **50***c*. Shielding **52** may be used to shield magnetic energy from the payload and the vehicle body. Payload fairing **12** levitates relative to payload attachment fitting **26** due to the repulsive forces provided by magnets **40***a*, **40***b*, and **40***c* relative to magnets **50***a*, **50***b*, and **50***c*. That is, the magnets are preferably oriented so the same poles are adjacent to each other. For example, the outer face of magnet **50***a* preferably is a south pole while magnet **40***a* is also a south pole. The opposite may also be true. By levitation, a gap **54** is positioned between payload fairing **12** and payload attachment fitting **26**. It should be noted that during launch, top surface **34** and top surface **42** or portions thereof may actually contact each other until the launch vehicle reaches a predetermined altitude so that a lower force is provided on payload fairing **12** that allows magnets **40***a* and **50***a* to maintain a gap **54** therebetween. Prior to the payload fairing **12** being deployed, gap **54** is formed by the magnetic forces of magnets. Thus, the shock forces of the deployment will not be transferred to the payload attachment fitting **26**. For example, above 3g's the top surface **34** contacts top surface **42**. Below 3g's gap **54** is maintained.

Referring now to FIG. **6**, a portion of launch vehicle **10** is illustrated coupled by a bolt **56** to payload attachment fitting **26**. In this embodiment, top surface **34'** is positioned at a angle relative to bottom surface **38'**. In this embodiment, a fourth slot **30**'D having a magnet **40**'D is illustrated. Likewise, ring **24** has an additional slot **48**'D with an additional magnet **50**'D.

In this embodiment as well, contact may be made between top surface **34** and top surface **42** when excessive force is provided on fairing **12**, such as during launch.

Referring now to FIG. **7**, a third embodiment of interface **28**" is illustrated. In this embodiment, intermediate surfaces **58**, **59** are formed on payload attachment fitting **26** while intermediate surfaces **60**, **61** are formed on fairing **12**. Intermediate surfaces **58**, **59**, **60**, and **61** connect respective side surfaces **36**" and **44**" with respective bottom surface **38**" and **46**". Payload attachment fitting **26** has top surface **34**", side surface **36**", and bottom surface **38**". Fairing **12** has top surface **42**", side surface **44**", and bottom surface **46**". Thus, both lip **32**" and ring **24**" have complimentary surfaces that have been modified from those shown in FIGS. **5** and **6** above.

Referring now to FIG. **8**, slots **30***a*, **30***b*, and **30***c*, and **48***a*, **48***b*, and **48***c* of each of the embodiments may be formed in the same way. The slots may each be formed using a keyhole slot **62** on each of fairing **12** and payload attachment fitting **26**. The keyhole slot may be continuous in the surface into which it is formed. However, a discontinuous slot may be employed. The slots preferably correspond to the shape of magnet **40***a* and **40***b*. A screw, adhesive or other fastener may be used to maintain the position of the magnets therein.

Referring now to FIG. **9**, various shock responses are illustrated with respect to the natural frequency thereof. The upper line corresponds to the standard clampband shock during payload deployment. The middle line corresponds to the payload fairing shock, while the bottom line illustrates a low shock clampband shock deployment. The maximum goal of the present invention is thus below the low shock clampband.

Referring now to FIG. **10**, a simulated test was performed with no shock rings, three rings, and a magnetic interface according to the present invention. Separation systems between the payload attachment fitting and the payload ate now used which reduces the shock on the payload. Such devices include clampbands and discrete separation nuts. The remaining dominant shock source is thus payload fairing separation. In operation, when the fairing and payload attachment fitting is assembled, the magnets levitate the fairing relative to the payload attachment fitting and maintain the gap thereby. During launch, excessive forces are generated pushing the payload fairing into contact with the payload attachment fitting. At an increased altitude, lower pressure or force is placed upon the payload fairing, thus the payload fairing is levitated relative to the payload attachment fitting and a gap is maintained therebetween. Thereafter, the payload fairing is commanded to deploy and thus the shock is not transmitted through the payload attachment fitting to the payload.

While particular embodiments of the invention have been shown and described, numerous variations and alternate embodiments will occur to those skilled in the art. Accordingly, it is intended that the invention be limited only in terms of the appended claims.

What is claimed is:

1. A launch vehicle assembly comprising:

a launch vehicle body having a first slot therein;

a first magnet disposed within said first slot;

a fairing assembly positioned adjacent to the vehicle body, said fairing assembly having a second slot therein, said second slot positioned opposite said first slot;

a second magnet disposed within said second slot so that said second magnet repels said first magnet,

said fairing assembly contacting the launch vehicle body when a predetermined force acts on the payload fairing and levitating relative to the launch vehicle body when a force below the predetermined force acts on the fairing assembly.

2. A launch vehicle assembly as recited in claim **1** wherein said first magnet and said second magnet comprise neodymium.

3. A launch vehicle assembly as recited in claim **1** wherein said launch vehicle body comprises a payload attachment fitting, said first slot disposed within said payload attachment fitting.

4. A launch vehicle assembly as recited in claim **1** wherein said first slot comprises a keyhole slot.

5. A launch vehicle assembly as recited in claim **1** wherein said second slot comprises a keyhole slot.

6. A launch vehicle assembly comprising:

a launch vehicle body having a lip therearound, said lip having a first upper surface, a first lower surface and a first side surface extending between said first upper surface and said first lower surface, said first upper surface having a first slot therein, said first side surface having a second slot therein and said first lower surface having a third slot therein;

a first magnet disposed within said first slot;

a second magnet disposed within said second slot;

a third magnet disposed within said third slot;

a fairing assembly having a ring positioned adjacent to the lip, said ring having an second upper surface adjacent to said first upper surface, a second lower surface adjacent to said first lower surface and a second side surface adjacent to first side surface, said second upper surface having a fourth slot therein, said second side surface having a fifth slot therein and said second lower surface having a sixth slot therein;

a fourth magnet disposed within said fourth slot;

a fifth magnet disposed within said fifth slot;

a sixth magnet disposed within said sixth slot;

so that said first magnet repels said fourth magnet, said second magnet repels said fifth magnet and said third magnet repels said sixth magnet.

7. A launch vehicle assembly as recited in claim **6** wherein said first magnet, said second magnet and said third magnet comprise neodymium.

8. A launch vehicle assembly as recited in claim **6** wherein said fourth magnet, said fifth magnet, and said sixth magnet comprise neodymium.

9. A launch vehicle assembly as recited in claim **6** wherein said launch vehicle body comprises a payload attachment fitting, said first slot disposed within said payload attachment fitting.

10. A launch vehicle assembly as recited in claim **6** wherein said first slot, said second slot and said third slot comprise a keyhole slot.

11. A launch vehicle assembly as recited in claim **6** wherein said fourth slot, said fifth slot and said sixth slot comprise a keyhole slot.

12. A method of operating a launch vehicle comprising;

positioning a payload fairing adjacent to a launch vehicle body;

contacting the payload fairing with the launch vehicle body above a predetermined force on the payload fairing;

levitating the payload fairing relative to the launch vehicle body below a predetermined force on the payload fairing; and

after levitating the payload fairing, releasing the payload fairing from the lunch vehicle.

13. A method as recited in claim **12** wherein levitating comprises levitating the payload fairing relative to the launch vehicle body by magnetic repulsive force.

14. A method as recited in claim **13** further comprising positioning a first magnet on the payload fairing and a second magnet on the payload fairing.

15. A method as recited in claim **14** wherein positioning comprises positioning the first magnet in a first slot and a second magnet in a second slot.

16. A launch vehicle assembly comprising:

a launch vehicle body having a first slot disposed in a payload attachment fitting;

a first magnet disposed within said first slot, said first slot disposed within said payload attachment fitting;

a fairing assembly positioned adjacent to the vehicle body, said fairing assembly having a second slot therein, second slot positioned opposite said first slot;

a second magnet disposed within said second slot so that said second magnet repels said first magnet.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

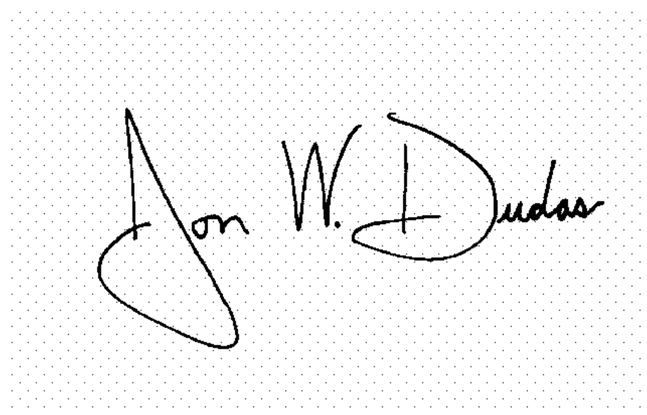
PATENT NO. : 6,695,261 B2
APPLICATION NO. : 10/073617
DATED : February 24, 2004
INVENTOR(S) : Mark Cleveland

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 6, lines 53-62 should read as follows:
--16. A launch vehicle assembly comprising:
a launch vehicle body having a first slot disposed in a payload attachment fitting;
a first magnet disposed within said first slot, said first slot disposed within said payload attachment fitting;
a fairing assembly positioned adjacent to the vehicle body, said fairing assembly having a second slot therein, said second slot positioned opposite said first slot;
a second magnet disposed within said second slot so that said second magnet repels said first magnet, and said fairing assembly contacting the launch vehicle body when a predetermined force acts on the payload fairing and levitating relative to the launch vehicle body when a force below the predetermined force acts on the fairing assembly.--

Signed and Sealed this

Fourth Day of September, 2007



JON W. DUDAS
Director of the United States Patent and Trademark Office